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(*Subject to Revision.*)

No. 898.*

REQUIREMENTS OF ELECTRICITY IN MANUFACTURING WORK.

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(Member of the Society.)

THIS paper briefly considers some essential features of electric power transmission in manufacturing work. † Earlier treatment of the subject has been varied and somewhat scattered, but not necessarily inadequate as far as the science had been developed at the time of its presentation. The statements and principles here set forth are founded upon what has been done, upon actual experience. Additional and valuable matter will no doubt be brought out in the discussion of this topic.

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* To be presented at the Milwaukee meeting (May, 1901) of the American Society of Mechanical Engineers, and forming part of Volume XXII. of the *Transactions*.

† For previous discussions on this topic consult *Transactions*, as follows:

No. 174, vol. vi., p. 461 : "Frictional Resistance of Engine and Shafting in Mills." J. T. Henthorn.

No. 191, vol. vii., p. 138 : "Frictional Resistance of Shafting in Engineering Establishments." S. Webber.

No. 354, vol. x., p. 823 : "Electric Motors for Shops."

No. 472, vol. xiii., p. 157: "Electric Power Distribution." H. C. Spaulding.

No. 712, vol. xviii., p. 228: "Friction Horse-power in Factories." C. H. Benjamin.

No. 738, vol. xviii., p. 861: "Electricity *vs.* Shafting in the Machine Shop." C. H. Benjamin.

No. 746, vol. xviii., p. 1,047: "Electrical Power Equipment for General Factory Purposes," D. C. Jackson.

No. 770, vol. xix., p. 467: "Electricity in Cotton Mills." W. B. Smith Whaley.

No. 806, vol. xx., p. 435: "On How Small a Tool Does it Pay to Put an Individual Electric Motor,"

No. 859, vol. xxi., p. 912 : "Systems and Efficiency of Electric Transmission in Factories and Mills." W. S. Aldrich.

Examples illustrating one or more of the principles involved might here be cited in detail, but complete descriptions of installations and valuable results of experience are now accessible on every hand. In fact, the whole development of this field of application of electricity is quite open and above board. It is founded upon common sense and engineering practice. It has therefore at once an advantage over many earlier and some modern or wished-for developments of electricity.

The demand for increased production is extending to all lines of manufacturing industry. It is created by the keen competition of trade and the necessity of filling orders promptly. The exigencies of business, therefore, are bringing directly to the front the question of this new motive-power in manufacturing.

Factories are not built in a day, but the ready extension of existing electrical supply service has increased the output from 30 to 40 per cent. per square foot of floor space. New machines and tools cannot always be obtained on telegraph order, but a resort to electric driving has increased the output of existing machines from 20 to 60 per cent. Workmen may not be had for the asking, but giving them electric-driven machines has increased the output per man from 10 to 30 per cent. All of this has been developed without any strikes or other than satisfactory regulation of wages by recognized premium and price-rate systems.

It is an axiom that the old-established concerns get the business. To-day they must guarantee delivery on time and at lower prices to keep their factories and mills in operation. Electric driving accelerates and intensifies production for the first requirement. It reduces the cost of production from 25 to 45 per cent for the second requirement. Of two manufacturers, each using the same size and style of latest machines, with equally skilled workmen, the one adhering to belt transmission,

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No. 882, vol. xxii., p. 366: "Power and Light for the Machine Shop and Foundry." F. R. Jones.

Special treatment outside of the Society *Transactions* will also be found in:

"Western Society of Engineers, Chicago," June, 1898, vol. iii., *Transactions*.

"American Institute Electrical Engineers," 1899, vol. xvi., *Transactions*.

"Institution of Electrical Engineers, London," *Journal*, July, 1900; vol. xxix., *Transactions*.

"Railway Master Mechanics Association, Report by Committee," *Railway Master Mechanic*, June-July, 1900; *Engineering News*, July 12, 1900.

"Franklin Institute, Philadelphia," January, 1901, vol. 151, *Journal*.

with its limited capacity and speeds, will probably fall behind in orders. With many manufacturers it is still a question whether the electric drive costs more to install and to maintain than the belting system. This can only be determined for each particular case as it arises. If it should cost more, it will still prove a profitable investment when it increases the output per day, per man, per machine, per square foot of floor space, increasing the quantity and enhancing the quality of the product while decreasing the cost.

It is no longer a question of the efficiency of electricity *vs.* shafting for power transmission. Nor is it a mere question of saving at the coal pile when only 2 or 3 per cent. of the total cost of production is to be charged to the fuel account. In many cases electricity has effected a saving during the first year that has more than paid for the change to the new system. Whether it is more or less economical than mechanical transmission depends upon circumstances. When properly installed and operated, electricity should have inherently all of the considerations in its favor.

The resulting economy of production and the ability to fill orders promptly are all in favor of the electric system. It may be compared to skilled labor,—high-priced, but very desirable from the standpoint of the economics of production. Few manufacturers still hesitate to employ high-priced skilled labor. Many more cling to antiquated methods of driving modern machinery operated by most skilful workmen. To-day, therefore, this question assumes very different proportions. The discussion has been shifted to the field of manufacturing economics, involving considerations of maximum output with given equipment, floor space and working force. It is a question of accepting and filling orders or of losing the business to those manufacturers who can take them.

The disciplinary value of electric driving cannot be ignored. The old easy-going belt system used to allow many a glance at the morning news, many a familiar chat during long and deep cuts. With the electric drive the operator finds it very convenient to be near his machine. The customary warning signals of slipping belts are no longer heard.

Satisfactory illumination should also be provided. No one will work by a smoky torch when he can have an arc or an incandescent lamp. Electric light must be supplied in these

times in all shops where they make a practice of doing a day's work the year round. Only a little wiring is required, and a small amount of extra power is necessary at the generating plant to drive machines and tools by electricity. In many instances electric lighting has paved the way for electric driving.

We have all had experience in getting men to "speed up" their machines. Tradition and custom are both against the operator who does much belt shifting. In the eyes of almost all journeymen and of some piece workers it is next to treasonable to change the rate of working. Even though paid extra, to do more than a day's work in many shops is still a crime against the union or other combination interested. The workman who attempts it soon finds a job elsewhere or is promoted. The electric drive changes all of this. A press of the button, a turn of the lever, and each piece of work can be executed at maximum speeds allowed by the temper of the tool steel. It forcibly illustrates Maxim's statement that American workmen find it pays to do as much as they can.

The ever-widening applications of electricity in manufacturing work show that it has fully proven its claim to a consideration. It is thoroughly reliable. It has come to stay. It fills the exacting requirements in this new field more economically and satisfactorily than any other system of power transmission. In the common forward movement of industry electricity is still in the van. It stands ready for any emergency within its province and so far has been equal to each new demand made upon it.

Aside, however, from all purely technical considerations of the application of electricity to manufacturing stands preeminently the question: does it pay? Many manufacturers have conclusively shown that the economies of production have been enhanced by their adoption of electricity, that its inherent advantages in this relation far outweigh all previously debatable questions of economy and efficiency of the electric drive compared with belting transmission and that even if there were no saving at the coal pile it would still not pay to return to the old method and lose orders.

I.—General Considerations.

1. *Electric Transmission in Manufacturing Work is a Means to an End:* Centralized power generation for light and manufacturing purposes; subdivision of the transmission system and

the motive-power equipment; execution of all classes of work, irrespective of its location; maximum efficiency of workmen, machines and labor involved; intensified production at best speeds and at the power limit of machines with improved quality, maximum output and reduced cost.

2. *Sanitary Considerations:* It is healthful, clean, and free from dirt, dust and dripping oil; it affords accommodations and facilities for proper lighting and ventilation; it removes dangers from overhead machinery shafting and belts; it reduces the sick list to a minimum; it insures quietness from absence of much unnecessary noise with older systems, and develops cheerfulness in workmen.

3. *Disciplinary Value:* It improves the *morale* and the *personnel* of workmen; it conduces to shop order and discipline, with the most economic use of the workman's time, quick handling of material and maximum efficiency of labor.

4. *Flexibility of the System:* Accessibility of all parts, adaptability to various uses, and portability of tools are inherent advantages.

5. *Reliability of Service:* It is free from any general breakdown, localizing casualties and stopping least machinery for repairs; no accident can affect the whole plant in any case of a modern electrical installation properly designed, equipped, and operated; it is more to be depended upon than any other system.

II. Economics of Electricity in Manufacturing.

1. *Electric Power Generation:* This system admits of centralized or concentrated power generation which is required for maximum economy. Distributed power generation in small and scattered units is very wasteful.

The electric power plant may be located to best advantage for fuel and water supplies, conveying and transportation facilities. It may be isolated from other structures, so reducing fire risks and insurance rates, especially where the boiler house is in a separate building.

The electric generating sets may be subdivided into similar and independent units. These may be operated at all times under the most economic condition of normal loads. This permits manufacturing work in any branch or section of the establishment as economically under part load as under full

load, on overtime and night shifts as during the day's work.

Electric light may be supplied from the power mains or from separate generators, as conditions require. In not a few cases of the introduction of electric driving the additional saving has been more than enough to pay for all of the lighting service.

The cost of generating electric power can only be a deciding factor when the total cost of power required is large compared to the running expense. The saving in fuel depends upon the cost of fuel, the average load, the amount of shafting and belting displaced.

2. *Electric Power Transmission:* The distances are short in factory service, the electric distribution being within one building or a group of buildings. The so-called line losses are therefore usually negligible in well-designed installations. Low voltages are employed in factory transmission. From 110 to 550 volts are the accepted limits at the present time in this country, either for direct- or alternating-current working at constant potential or pressure. The economics of the various systems can be only satisfactorily discussed with reference to any given project or installation.

The following are recognized methods of distribution, for electric light or power, or both, in manufacturing work:

Two-wire and three-wire systems, for direct or alternating currents.

Multi-circuit system for direct-current multi-voltage service.

Single-phase, two-wire alternating current.

Two-phase, three- or four-wire alternating current.

Three-phase, three- or four-wire alternating current.

Composite system, direct current and single-phase or two-phase alternating current on the same wires.

3. *The First Cost of Electrical Installation:* This will usually be higher for an electrical than for a mechanical transmission. The interest on first cost will rarely be a determining factor. It will be more than offset by the manufacturing economies elsewhere effected and by the reduced cost of shop buildings incident to the use of the electric drive.

4. *Maintenance of Electric System:* The cost of maintenance is a minimum. The depreciation is less than in any other system.

The saving effected is much more than sufficient to pay for all

of the incidental repairs and renewals to the electrical machinery or the wiring system.

Attendance and supervision are largely centralized and reduced to a minimum compatible with efficient service, owing to the reliability of the system.

Electric generators and motors are the simplest types of motive-power machinery that can be used in the development of power transmission for manufacturing work. They have the fewest parts requiring any renewals. They require practically no repairs.

Electric machines will either work or not work. They soon make their wants known. They cannot be maintained in wasteful operation, as is the case with every other kind of motive-power machinery. Standardization of this class of electrical machinery has facilitated repairs. They are quickly and easily made, at minimum cost and with least interference with the routine work of the establishment. Small electric motors in general require more frequent attention and renewals than larger machines.

Belt tightening or lacing in the old system stops work on that secton, and stops all work if it chances to be the main driving belt. Any similar casualty in the electric system is remedied at once by throwing into service another line, or a jumper, or a relay bus-bar.

III. Influence of Electric Transmission upon Factory Buildings.

The design, plan, and arrangement of manufacturing establishments are not now dictated or controlled by the new electric transmission, as always has been the case with the old mechanical system. Factory and mill construction is undergoing radical changes incident to the electric transmission of power. There is now a superior adaptation of the building to manufacturing work and sanitary requirements, with higher ceilings for light, ventilation, and overhead transportation. The cost of buildings is reduced to a minimum. The electric drive does not require the heavy construction of walls, overhead work, and roof trusses demanded by shafting transmission.

The site for buildings may be chosen independent of power considerations and located on most suitable ground. There is no necessity for buildings being placed around or adjacent to

the power-house, as required for mechanical connections to engines or turbines. Grouped shops may be arranged in best manner to facilitate economic production and the handling, conveying, and transportation of material and work. Detached buildings, a tendency of certain lines of modern manufacturing development, are feasible and the work therein facilitated by electric transmission. The isolation of various shops, departments, and workrooms for manufacturing or insurance reasons may be carried to any extent with the electric system without impairing its efficiency or economy. The output per square foot of floor space is a maximum with electric transmission.

IV. Influence of Electric Transmission upon Workshop Expansion.

Future areas of work may be planned and arranged for with the utmost freedom and entirely irrespective of power considerations. They can be located as desired, on separate floors, in various departments or in detached buildings. Original provision for prospective development is not necessary in the electric system, but is required by shafting transmission. There is no expense for contemplated additions till they are actually installed as required.

Permanent additions to the electric generating plant and the distributing system are made with a gradual and pro rata outlay of capital, instead of in disproportionate blocks of new equipment, as required by mechanical transmission.

Extensions of electric transmission and new centres of power distribution may be established at any time and of reasonable capacity, anywhere and at any distance, at minimum cost for labor and material. There is no crowding, overloading, or interference with existing conditions, or with the daily progress of routine work. Temporary extensions, to meet sudden demands for power at any point, are quickly made by running to the desired location electric wires or cables. These are easily removed when no longer required and as readily used elsewhere for similar purposes. The shifts are made with the least expense of time and labor in handling, and with no accompanying waste of material to suit different conditions.

Auxiliary power is always at hand for emergencies and to almost any reasonable extent, on account of the reserve nature of the electric supply.

V. Influence of Electric Drive upon Arrangement of Machinery.

The floor space required per machine or tool is reduced to a minimum.

The alignment of overhead shafting is no longer necessary.

Clear overhead room is provided for handling all classes of heavy work. The crowding and complications arising from overhead shafts and belts are avoided.

Location of machines and tools may be made to suit the requirements of the work and the available floor space. The product may then be finished with least time and labor, with least handling and transportation, and in the most efficient and economic manner.

All the conditions of work and of labor may be arranged to handle tools and material to the best advantage with freedom of workman's movements and facility in executing manufacturing operations.

VI. Changing from the Old to the New System of Driving.

When alterations or additions in power transmission are required, it is the invariable practice in many modern shops to extend in the line of electric driving. This is notably the rule where electric supply is already at hand for either lighting or power service. In the rehabilitation of an old establishment some of the shafting transmission may usually be combined with the electric drive, as in the so-called group system. Much can be done to improve the power transmission if existing lines of shafting are divided into the most economic sectional lengths, determined by the speed, character of load, and kind of work. Electric motors will prove valuable adjuncts if installed to drive these sections independently. The electric drive is an economic and flexible auxiliary, supplementing the earlier and rigid mechanical power transmission. Such partial introduction of the new system, especially if an electric lighting plant is already in service, will early develop its advantages. It will defray the cost of installation and maintenance by greater economic production.

Scrapping the old to make room for the new involves the same economic questions in the case of power transmission as in that of manufacturing machinery. Productive machinery

should not in general be scrapped while there is retained the old system of belt driving, with its inherent power and speed limitations. The increased output of the old machine, electrically driven, will frequently equal that of a new machine, belt driven, and turning out the same kind of product.

VII. Application of the Electric Drive.

1. *Individual Driving Without Intermediate Gearing:* The armature of the motor is mounted on the main spindle of the machine. The power is most directly applied, with ideal adaptation of tool to work.

It requires more or less special adaptation of motor to machine, with rarely any marked changes in the structural design of the latter.

2. *Individual Driving with Intermediate Gearing:* The motor is conveniently mounted on the frame of the machine and drives it through the intervention of the ordinary gearing.

It requires no special adaptation of motor to machine. Any suitable motor may be used on any machine.

3. *Advantages of the Individual Drive:* The workman has the most perfect control of all factors entering into the economics of production. There is maximum economy in the application of power.

The speed control and the output are independent of any other machine. They are no longer limited by the speed of the line shafting. Machines and tools may now be worked to the limits of their respective capacities.

The productive efficiency of the machine is increased. It may be operated at all times up to the power limit, reducing time and cost of labor for any given product.

The choice of the individual drive depends upon the power required, the size of the machine, the time it is in service, and the value of the product.

The individual motor drive is usually adopted where the machine is in use only part of the time, and in sizes as small as two or three horse-power, and requiring wide variations in speed and power for maximum output quite independent of the first cost. For large machines this method reduces the power losses to a minimum. It is particularly advantageous for shears, punches, and a class of repair shop tools requiring power only at intervals. The constructive details and design of direct-

driven machines are not usually altered to any extent; secondary speed changes are obtained by the usual change-gear and mechanism; in special cases of large tools, a range of speeds is sometimes best provided by a special variable-speed motor.

4. *Group Driving:* A few large electric motors are employed independently driving sections of shafting of most economical length. This method is thus adapted for driving a number of small machines, with no particular requirements in speed or in power; or for most economical manufacturing along special lines; or for driving any section on overtime or night shifts; or for independent driving of separate floors, departments, or detached buildings.

The maximum economy with the group system can only be secured when all of the machines so driven are in constant use, at best speeds for maximum output. This dictates grouping machines as far as practicable of the same size, style, functions, speed and power requirements, having due regard to the work to be executed. Sectionalizing the power transmission by substituting electric motors for either the main or section belts secures partial advantages of the new system side by side with the old, and is frequently resorted to in old establishments adopting new methods.

5. *Individual and Group Driving:* The most general requirements of factory transmission can all be met by an intelligent combination of these two methods of electric driving.

The first cost of installing the individual drive will generally be from 2 to 5 per cent. higher than for the best group system, when all other considerations are the same. The individual drive is more economical in the use of power than the group system, especially if in the latter only a limited number of grouped machines are in use at any one time, at average loads.

6. *Portable Tools and Appliances:* The extreme flexibility of the electric system invites the widest use of portable tools and appliances. A flexible heavily-armored cable gives any desirable radius of action, with no expense to maintain as a part of the transmission system, with no danger or difficulty in handling, and requiring least time and labor for any immediate shifting of tool or work. Least used tools need not occupy floor space when not in operation. Most favorable economic relations may, therefore, be secured in many lines of manufacturing work,

especially of the heavier grades. Almost all required tools may be taken to and operated at the work in hand. Time is saved in not having to shift and adjust the work to the machine or tool. Several operations may be carried on at one time by bringing different tools to the work, each independently driven and operated.

7. *Electric Transportation and Conveying:* Electric hauling by surface or overhead systems of distribution, electric conveying and telpher systems, electric cranes, hoists, lifts, and elevators, are all well-developed fields, and present no unusual nor insurmountable difficulties when installed as a part of the regular electric system of a manufacturing establishment. Tools are taken to the work, or machines and tools are quickly served with material and work, reducing the cost of all handling to the lowest terms in a field of non-productive labor that has formerly been very expensive.

8. *Electric-Driven Auxiliaries:* With an established electric supply service for all manufacturing work it is an economic step to drive by electricity all auxiliaries, as pumps, fans, blowers, air compressors, etc.

VIII. Selection of Equipment.

1. *Factors Determining Choice of the Electric System:* Each manufacturing industry has its own inherent requirements. No general rules can be given, but every case must of necessity be studied and developed by itself with a thorough preliminary survey of all conditions and requirements. One successful system cannot furnish precedent for another.

In general, the following lines of inquiry should be freely investigated before choosing any system for power transmission in manufacturing work: the size of the establishment; the area to be served; the arrangement and grouping of shops, departments or buildings; the arrangement, types, and sizes of machines or tools to be driven; the variety of speeds required; the character of the loads involved; the kind of work to be executed; the economics of fuel and water supplies.

The above items should have been predetermined from the standpoint of most economic production. They should in no wise be influenced by questions of power transmission. How to drive the machinery in a new and modern manufacturing plant should be a second and not a first consideration. It should be

determined by, rather than itself determine, the conditions for economic production.

2. *Interchangeability Throughout the Electric System:* It should be possible to drive similar apparatus and motors from any point of attachment to the wiring system. Greater flexibility is thereby secured, added facilities provided for use of portable tools, and readiest extension made of plant and distributing system at any time. Preferably have one, and only one, electric system if it can be secured by intelligent consideration of all present and the most probable future requirements. This does not necessarily imply that it is best to have one single circuit for all kinds of service required in a manufacturing establishment, as light and power; but it should not be required to use different circuits for the same service, as portable tools.

3. *Uniformity of Electrical Equipment:* Generating sets and motor equipments should be standardized as far as possible in the case of any given establishment. These machines, as well as all their parts, should be readily obtained in duplicate at any time. This is particularly important in making additions and extensions in the group system, where it may be required to change from a smaller to a larger motor at any time to accommodate more machines on a given section. It cannot be advantageous to experiment with different styles and types. Electrical machinery to-day is so far standardized, and its performance predetermined, that there can be no excuse for not selecting that style and type best adapted to any given factory.

4. *Power Required as a Basis for Size of Electric Motor:* The load diagram for any machine will furnish the best data for determining the proper size of motor. It may be readily obtained under the working conditions of the machine by using a test motor.

In almost all metal-working industries the power required is subject to extreme fluctuations, and may be very heavy, at times, while the bulk of it will be quite light. It is not necessary to install an electric motor to carry, for any length of time, such sudden and heavy loads as will be shown by the peaks of the load diagrams for the several machines, or the sudden initial throw of the ammeter needle.

The limit of overload is fixed by the allowable rise of temperature, and can readily be predetermined for any given electric motor. In general, the surface temperature of the motor

field coils, as measured by a thermometer, should not exceed from 35 to 45 degrees C., with a maximum limit of 50 degrees C., after an overload run of from six to eighteen hours, as may be specified by the builders.

Starting load currents are of course high, and may be from two to three times the normal current, as in the case of overloads, for brief periods. Individual drives require proportionately larger motors to enable them to carry alone the heavy overloads. Group drives require only normal load motors, as it will rarely ever occur that the several grouped machines are all carrying overloads at the same instant. Motors for this service may often be much smaller than would be dictated by the combined load diagram of the machines forming the given group or section. In no case will they require to approach the maximum, or the sum of the maximum, loads of the various machines. Group system load curves will be smoothed out considerably. In all electric motor installations there should be ample power provided, rather than a narrow margin only to work upon. Increasing loads are almost sure to arise in time. A motor of ample size gives that reserve power so characteristic of the electric system, if properly installed.

5. *Character of Loads in Manufacturing Work:* Load curves and diagrams of individual machines, groups, sections, and the entire plant, only can be relied upon in estimating the character of loads being carried or likely to be carried under similar conditions. The load factor, the ratio of the maximum to the average load, for any given time on any part of the system, should be as high as possible for best working efficiency and economy. It may be largely influenced by the way the operator handles his motor. Whatever the kind of load, uniform or variable, light or heavy, continuous or intermittent, suddenly fluctuating or periodically variable, it must be carefully investigated before installing electric motive-power. In certain instances flywheels may be useful and for the same mechanical reasons as elsewhere employed in machinery.

6. *Speeds of Manufacturing Machinery:* The speeds should be predetermined by the conditions for most economic maximum output, and so fix the range required for the electric motors. In no instance should the reverse be the case. In many cases of individual drives it may be best to secure the speed reductions mechanically, as by the ordinary change-gear. It is not

necessary nor advisable in all cases to secure the same by mounting the motor armature directly on the spindle of the machine. Provide motors with speeds consistent with the range of change-gear, and gear down rather than up.

7. *Electric Generators Required in Manufacturing Plants:* The style and type should be largely determined by the kind of service to be supplied, the size by the normal and overload conditions as shown by the plant load diagrams, with due considerations given to special conditions and variable loads.

The actual normal capacity of the generator will be chiefly determined by the length of time the various motors are in use, rather than by their normal or aggregate capacity. It may happen, owing to the intermittent use of machines and motors, that the generating plant may be reduced to 50 per cent., or even to 20 per cent. of the aggregate normal capacity of the motors out in the establishment. An increase of the electrical system can only be intelligently made from a careful study of the load curves of the existing installation, and using it as a basis for comparison with the probable load curve under the proposed conditions. There should be judicious subdivision of the generating plant into units, preferably of the same size and style, that they may be readily interchanged and duplicated at any time, with one or two relay units for emergencies and extra rush seasons of work. All generating units used in manufacturing installations will necessarily be of such size as to warrant their being driven by direct connection to engines or turbines. If generators required are too small to warrant direct connection, the establishment is too small to warrant an introduction of the electric drive.

8. *The Electric Wiring and Distributing System:* All wiring should be done in accordance with the "National Electric Code," being the rules and requirements of the National Board of Fire Underwriters. Separate service circuits, from the same or separate bus-bars, may be provided to advantage, for lighting and various power uses. Sub-stations, or sub-station switchboards, should be provided for separate shops, floors, departments, or buildings, making it unnecessary to run a separate set of wires back to main switchboard for each service.

9. *Indirect Electric Distribution:* Indirect distribution, through the use of accumulators, converters, or transformers may be found expedient under certain conditions. For the three-wire

systems, some type of accumulator or motor-generator balancing set is almost essential for efficient regulation. The accumulator may render as invaluable service in certain kinds of factory installations, as in iron and steel mills, as it is now rendering traction work, where the character of the load variations of the former is somewhat analogous to that of the latter. The loss in the battery is very small and entirely negligible compared to the advantages to be derived from its use in manufacturing plants of the type mentioned.

IX. Losses in Factory Transmission.

The inherent losses common to all systems of factory transmission are due to the intermittent and irregular use of the machines driven. These are reduced to a minimum with the electric drive. There is no consumption of power when the motor and machine are not in operation. There are no power losses when the motor is not in use, no so-called dead load losses, due to mechanical friction of the shafting system, no transmission losses in the line when the electric current is not required.

Electric generators and motors, when in operation at uniform speeds, have, generally speaking, but two kinds of losses: the first is a constant quantity depending upon the size and type of machine; the second is a variable loss proportional to the square of the current in the armature circuit. The electric line and other wiring has a loss proportional to the square of the current carried. The cost of waste power in the mechanical system becomes excessive at light and frictional loads. It is saved in the electric system, in which the constant losses are minimized and the variable losses are throughout proportional to the amount of work being done.

X. Efficiency of Electric Transmission.

The efficiency of the electric system under normal conditions shows high maintained values, from about 25 to 35 per cent. underload to the same amount of overload, for the individual generators and motors, as well as for the aggregate efficiency of the installation. In mechanical transmission there is a constant falling off in efficiency at various underloads in every part

of the system, owing to the inherent losses due to mechanical friction, which losses are constant at all loads and constant speeds. It is not a question so much of the individual efficiencies, in either case, as of the aggregate or combined efficiency, from engine or turbine shaft to machine or tool. The performance should be considered and compared at proportional parts of the full load as well as at normal loads. The mechanical efficiency of all manufacturing machines is almost invariably low. It is possible materially to effect it by efficient motors properly selected, installed, and operated.

The all-day efficiency may be made higher with the electric drive than with any other system, as the amount of time is minimized during which machines and tools are necessarily idle.

XI. Operation and Testing of Factory Installations.

1. *The Generating Plant.* As far as practicable, each unit should be operated at its normal capacity—additional units to be switched in as may be required by the manufacturing conditions.

2. *The Motors.* Rarely the case that any machine or tool is started from rest with full load upon it. Motors may be started best under the usual friction, or light loads on the machines, as in the belt systems. When the machine is brought up to proper speed, work may be thrown on to it. In this respect the practical operation of an individual electric drive follows closely that of the belt system.

It is always possible to tell exactly what is going on in an electric drive, both in kind and amount of useful work, as well as in matter of wastes and losses. Power measurements are made at any point by ammeter and voltmeter, or by a wattmeter alone. A special test motor of known performance lends itself admirably to comparative tests of the performance of machines and tools under various conditions. Workmen may know at any moment whether they are driving tools or machine to best advantage for maximum output at best speeds.

The definite power required for definite work may be determined and charged to each machine, tool, or piece of work, and so make up the shop cost of production more exactly than by any other system. The power lost in friction of individual machines when running empty may be obtained with equal facility

and compared with that required in doing useful work. It will be found that the latter increases almost directly as the resistance being overcome by the machine in its operation under working conditions. The power required by the work is a small per cent. of the total power delivered to the machine.